Diffuse reflectance of dip-coated films of barium sulphate in polystyrene

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Introduction

The use of lenses and specular reflecting surfaces (mirrors) to direct light in optical instruments is commonplace. However, light may also be directed within a closed hollow volume having diffuse internal reflecting surfaces and a small exit hole – if the volume is round, this is called an integrating sphere. This is a critical component in the homogenisation of light and used when determining the efficiency of luminescent materials and light sources. Modern commercial integrating spheres employ Teflon-based materials for the internal diffuse reflecting walls, which produces excellent optical characteristics but at high financial cost. Barium sulphate powder has been identified as an eminent diffuse reflecting material and the aim of this work was to assess whether effective diffuse reflective coatings could be formed by dip-coating a substrate in a suspension of barium sulphate powder in a solution of polystyrene dissolved in toluene.

Experimental procedure

- For the solution, 50.6 g of polystyrene pellets (192 000 g/mol) was dissolved in 200 ml of toluene.
- Substrates of glass slides and sand-blasted steel sheets were dip-coated (Figure 1) using a withdrawal rate of 300 mm/min.
- This was repeated for various concentrations of barium sulphate powder.
- Multiple layers were produced with a barium sulphate concentration of 240 g/dm^3.
- A PerkinElmer Lambda 950 UV-Vis Spectrophotometer was used to determine the direct and diffuse transmittance, and diffuse reflectance of the samples.
- Scanning electron microscopy (SEM) was performed on the barium sulphate powder to gauge the particle size.
- Positive secondary ion mass spectroscopy (SIMS) of a film was done to visualise the orientation of the barium sulphate within the coatings.

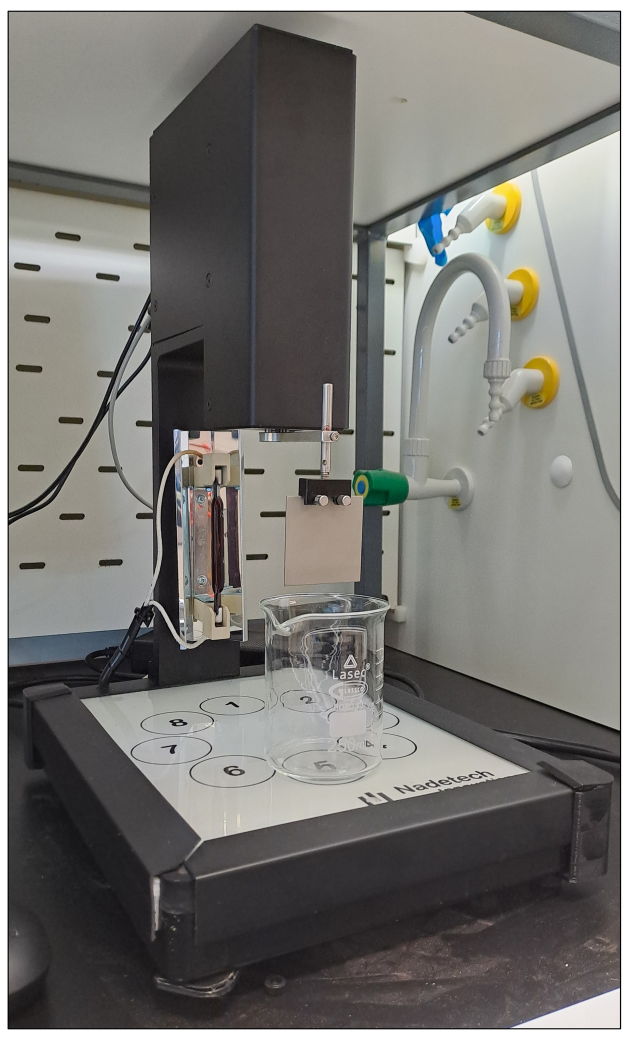


Figure 1: Nadetech Innovations dip-coater.

Results and discussion

- Scanning electron microscopy showed that the barium sulphate particles had the form of irregular plates varying from 0.1 - 2 µm in size (Figure 2).
- Using the mass deposited for the pure polystyrene films, their thicknesses were estimated near 20 µm, so the films were significantly thicker than the size of the powder particles.

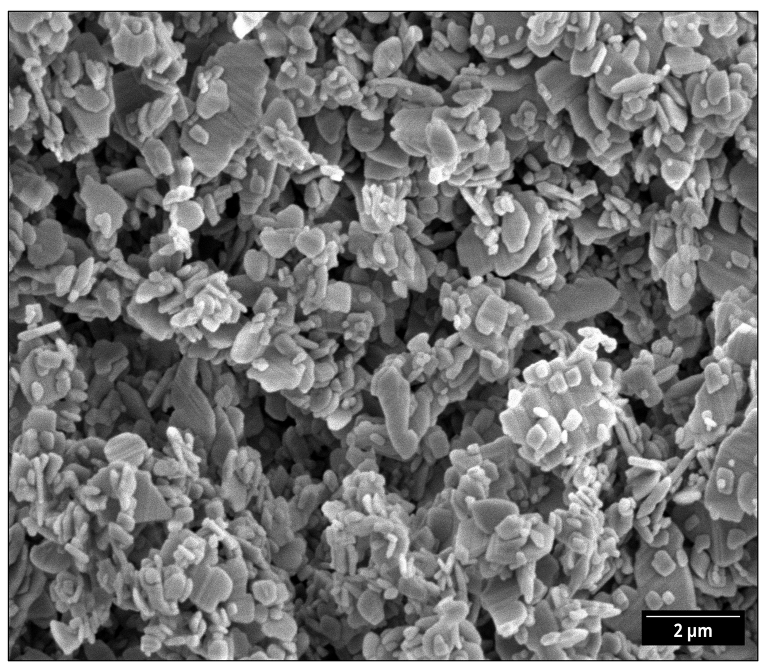


Figure 2: Electron microscope image of barium sulphate powder.

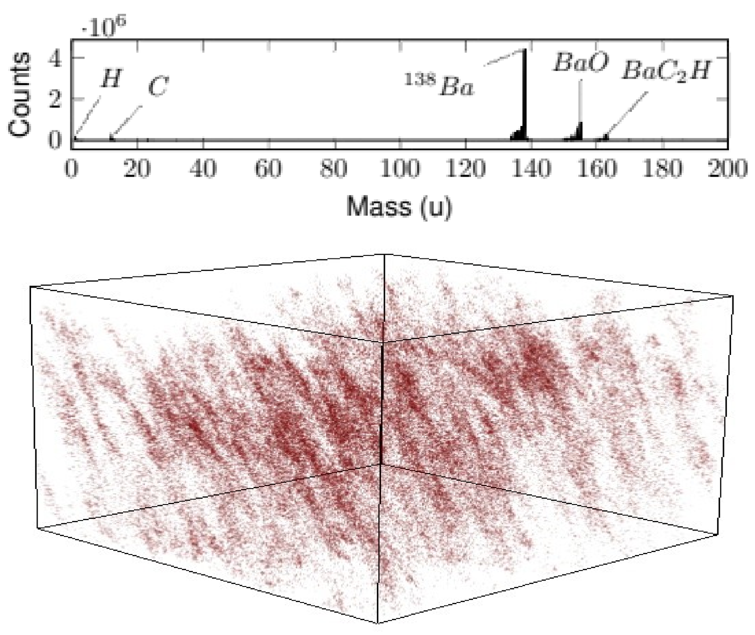
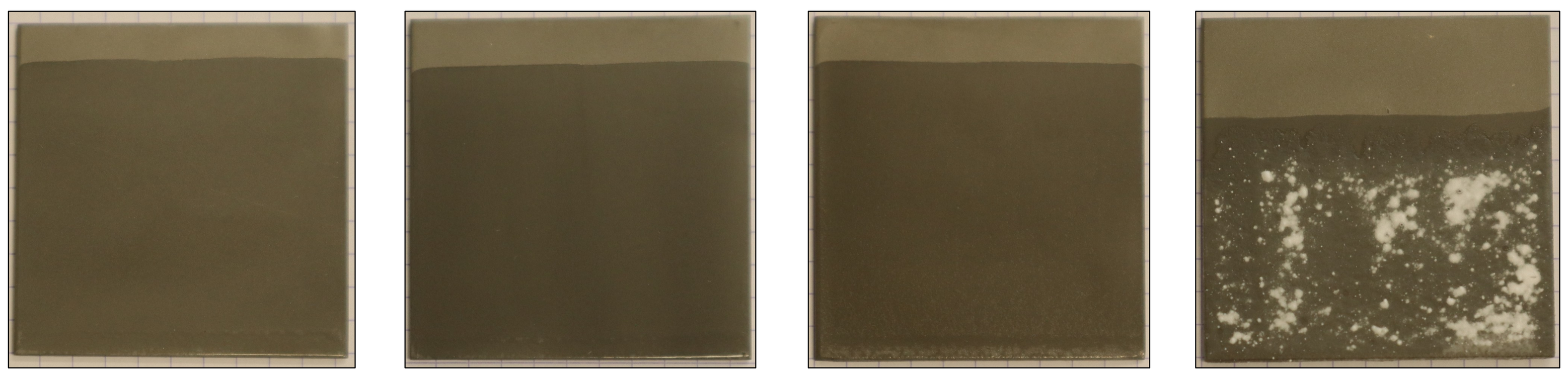


Figure 3: SIMS mass spectrum (top) and 3D reconstruction of barium compounds (bottom) from barium sulphate within polystyrene.

- The barium sulphate particle distribution were slanted within the polystyrene (Figure 3). This is due to effects such as surface tension and gravity during the dip-coating process.
- Coating the steel plates (Figure 4), even to the maximum barium sulphate loading, had little effect on their diffuse reflectance (Figure 5). This is ascribed to the fact that the diffuse reflectance of the coating was comparable to that of the steel plate itself.
- Single coatings with barium sulphate masses below 60 g had marginal effects on the diffuse reflectance and transmittance of the glass slides (Figure 5). Greater loads exhibited improved reflectance and reduced transmission. Multiple coatings improved the reflectance to near 50% at 550 nm and reduced the diffuse transmittance to 30%. Glass slides with multiple coatings are shown in Figure 6.
- Multiple layers and high barium sulphate loadings strongly reduced the direct transmittance of the glass slides (Figure 5). This is indicative of strong scattering.
- The coatings were likely inadequate due to the similarity in the index of refraction between barium sulphate (1.64[1]) and polystyrene (1.60[2]).
- Air inclusions may enhance the scattering of the films.
- The coatings delaminated from the substrates after a period of a week.



(a) (b) (c) (d)

Figure 4: Sand-blasted steel plates coated from polystyrene in toluene solutions with (a) none, (b) 15 g, (c) 30 g, and (d) 60 g of barium sulphate.

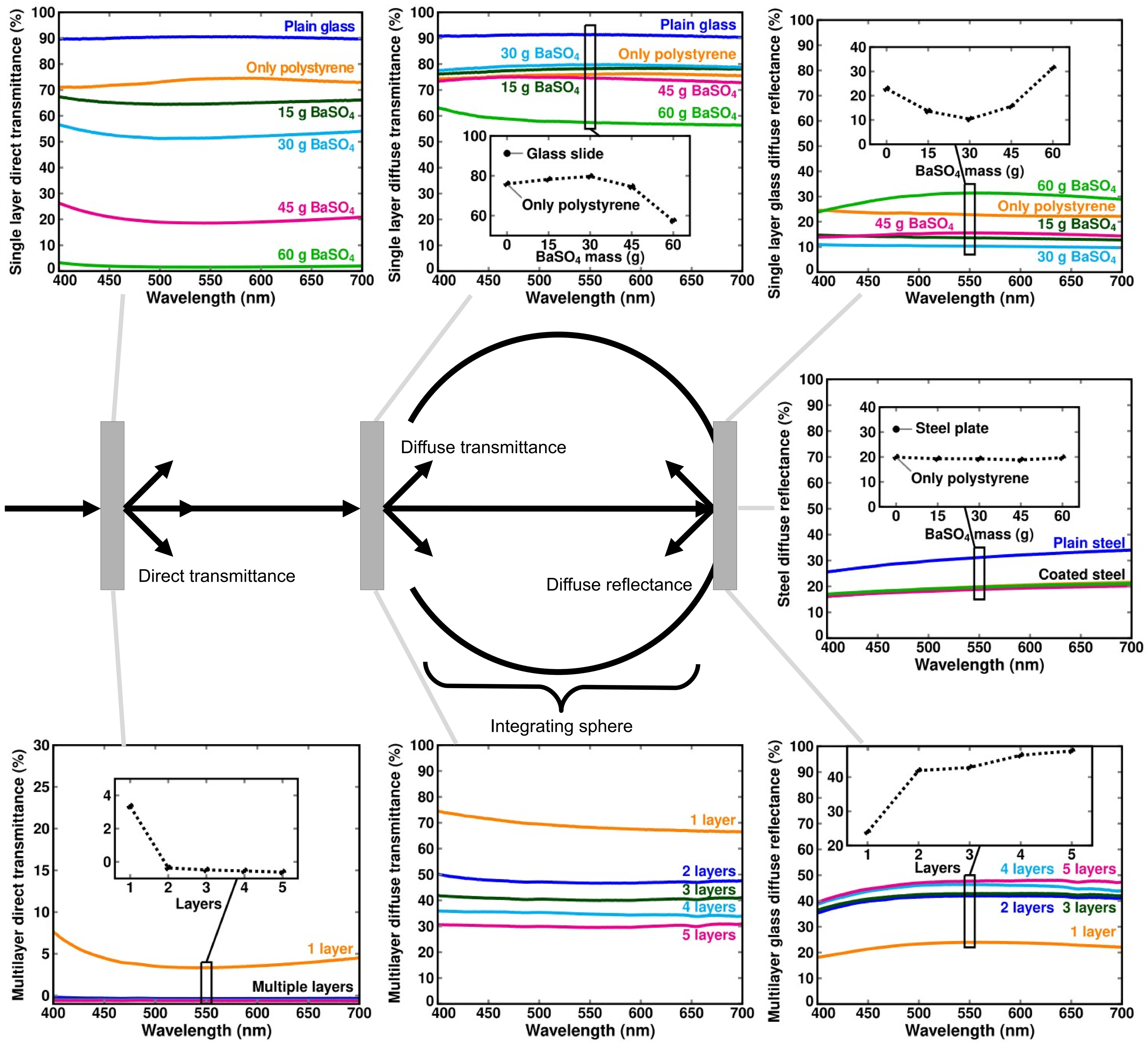


Figure 5: Optical measurements of barium sulphate and polystyrene coatings.

(a) (b) (c) (d) (e)

Figure 6: Glass slides with (a) 1, (b) 2, (c) 3, (d) 4 and (e) 5 layers.

Conclusions

- Single coats of barium sulphate in polystyrene do not produce effective diffuse reflectance coatings.
- Multiple coating improve the scattering of visible light, yet only increase the reflectivity to approximately 50%.
- This is attributed to the similarity in barium sulphate and polystyrene's index of refraction.
- Barium sulphate encased in polystyrene does not produce a reflective coating suitable for diffuse reflective surfaces. It is thus not suited for the interior lining of an integrating sphere.

References

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